National Aeronautics and Space Administration

UAS Pilot Evaluations of Suggestive Guidance on Detect-and-Avoid Displays

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Introduction

- UAS in the NAS Project Objectives
  - Address technical and safety barriers to the expansion and integration of Unmanned Aircraft Systems (UAS) into the National Airspace System (NAS)
    - Currently limited to public purposes (e.g., military training) in restricted airspace
  - Produce research findings that guide the development of RTCA Special Committee 228's Minimum Operational Performance Standards (MOPS) for UAS
    - Identify minimum DAA display, alerting, & maneuver guidance that result in acceptable pilot performance and response times

- Detect and Avoid (DAA)
  - Existing regulations for manned flight operations require onboard pilots to "see and avoid" other aircraft in order to remain well clear (14CFR, Sec 91.113)
  - Unmanned operations will require a traffic display equipped with a "detect and avoid" system that provides the information necessary for self-separation
    - Effectively substituting for a manned pilots' ability to see outside of their aircraft under normal operating conditions

Background

- Past studies have explored the minimum visual information requirements necessary to perform UAS pilot-in-the-loop DAA tasks
  - Predictive displays with integrated maneuver guidance tools for conflict avoidance have improved pilot performance compared to displays with less information
    - Less near midair collisions (NMACs) (Friedman-Berg et al., 2014)
    - Reduced severity of well clear violations (Bell et al., 2012; Santiago & Mueller, 2015)
    - Quicker response times (Rorie & Fern, 2015; Rorie et al., 2016)
    - Higher pilot preference ratings (Monk et al., 2015)
  - Advanced guidance tools were tightly coupled to the vehicle control interface
    - Auto-populated maneuver resolution directly into steering window

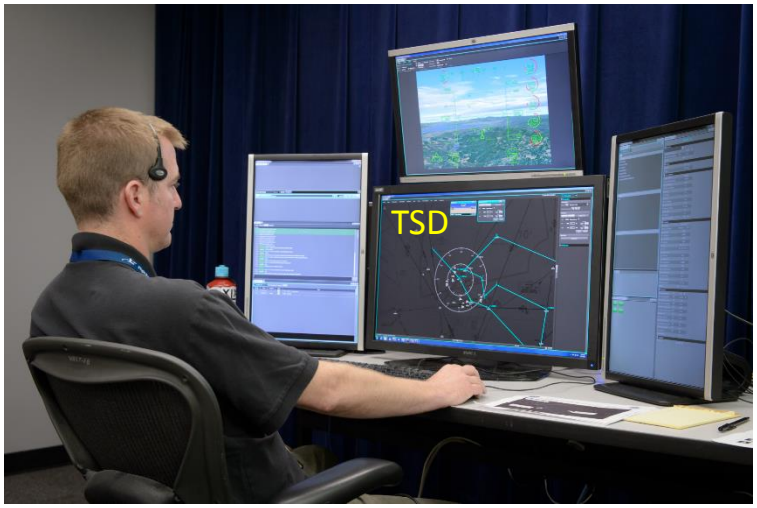
Purpose

- Examine pilot evaluations of four DAA displays with varied levels of suggestive guidance to further determine minimum information requirements for UAS ground control stations
    - Suggestive guidance tools decoupled from command-and-control interface
        - Presented range of solutions as opposed to a directive command

- *Are the pilots' perceptions of the DAA system consistent with their objective performance?* (Rorie et al., 2016)

Method

- Participants
  - 16 active duty UAS pilots
    - μ_{age} = 37 years old
    - Unmanned flight experience
      - Civil: 30 hours avg.
      - Military: 1100 hours avg.
    - Manned flight experience
      - Civil: 575 hours avg.
      - Military: 1760 hours avg.



- Simulation Environment
  - Vigilant Spirit Control Station (VSCS)
    - Developed by Air Force Research Laboratory (Feitshans et al., 2008)
    - Primary field of view was Tactical Situation Display (TSD):
      - Command-and-control interface
      - DAA guidance & traffic
      - Mission route

Experimental Design

- DAA Display Configuration
  - Minimum Information Only (Info Only)
  - No-Fly Bands
  - Omni Bands
  - Vector Planner

- Minimum set of traffic information was constant across all displays
  - Intruder Location & Direction
  - Relative Altitude
  - Vertical Trend Arrow
  - Call Sign (within data tag)
  - Ground Speed (within data tag)
  - Multi-Level Conflict Alerting Structure

DAA System: Multi-Level Alerting Structure

Symbol	Name	Pilot Action	Time to Loss of Well Clear	Aural Alert Verbiage
	DAA Warning Alert	• ***Immediate action required*** • Notify ATC as soon as practicable after taking action	25 sec (TCPA approximate: 60 sec)	"Traffic, Maneuver Now"
	Corrective DAA Alert	• On current course, ***corrective action required*** • Coordinate with ATC to determine an appropriate maneuver	75 sec (TCPA approximate: 110 sec)	"Traffic, Separate"
	Preventive DAA Alert	• On current course, corrective action ***should not be required*** • Monitor for intruder course changes • Talk with ATC if desired	N/A	"Traffic, Monitor"
	DAA Proximate Alert	• Monitor target for potential increase in threat level	N/A	N/A
	None (Target)	• No action expected	X	N/A

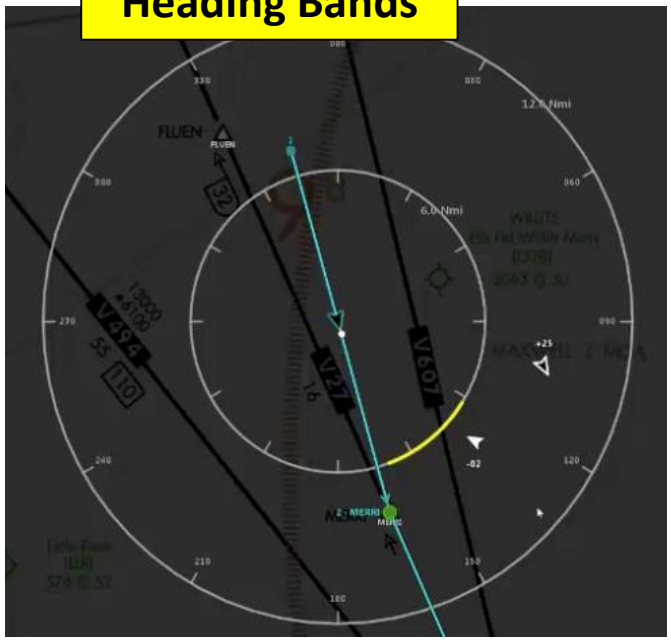
Display Configurations

1. Info Only
   - Standard intruder information and multi-level alerting presented (no guidance)
     - Intruder Location & Direction
     - Relative Altitude
     - Vertical Trend Arrow
     - Call Sign (within data tag)
     - Ground Speed (within data tag)
     - Threat Level

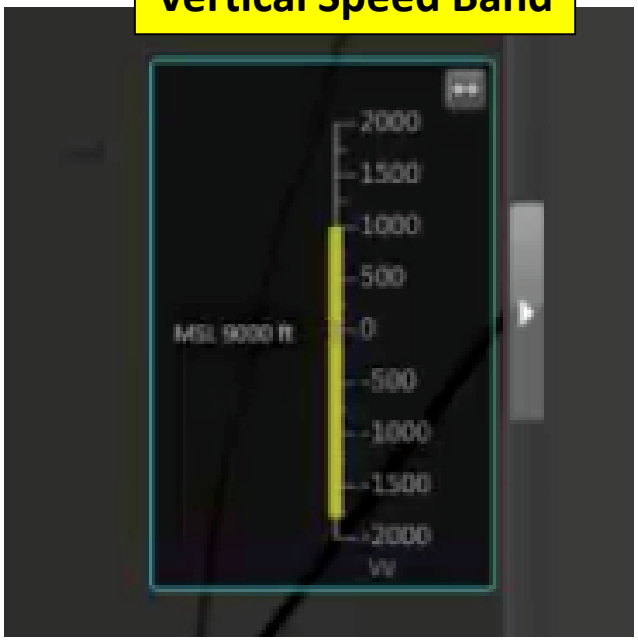
Display Configurations

2. No-Fly Bands
   - Indicated headings/vertical speeds that would lead to an eventual loss of well clear
     - Maneuver outside of banding to maintain well clear

Heading Bands

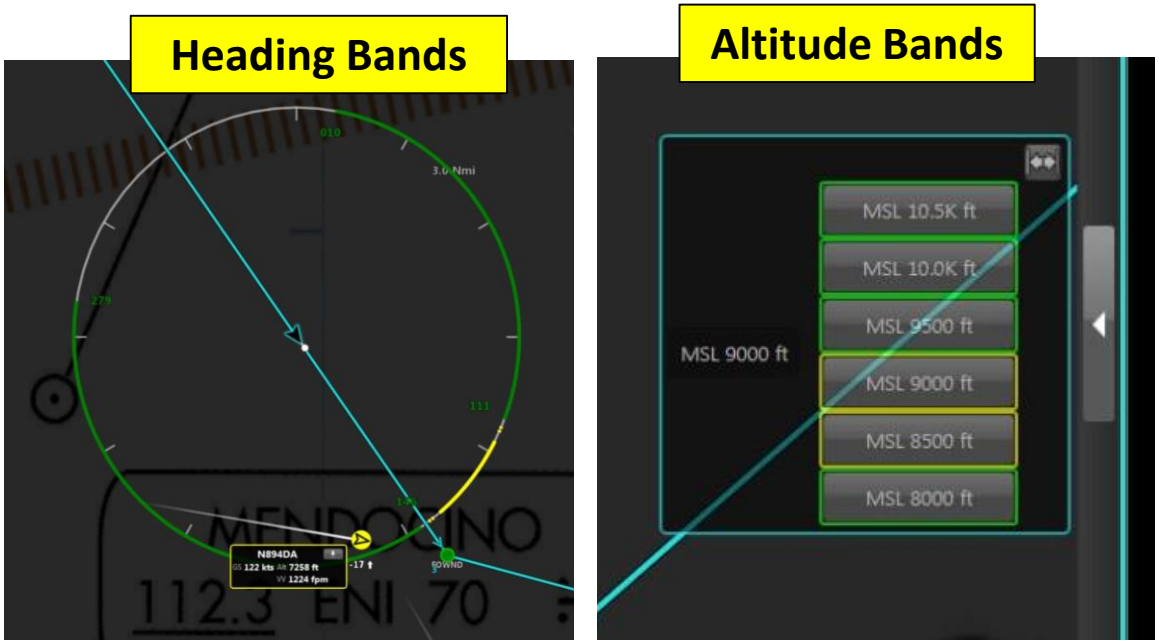


Vertical Speed Band



Display Configurations

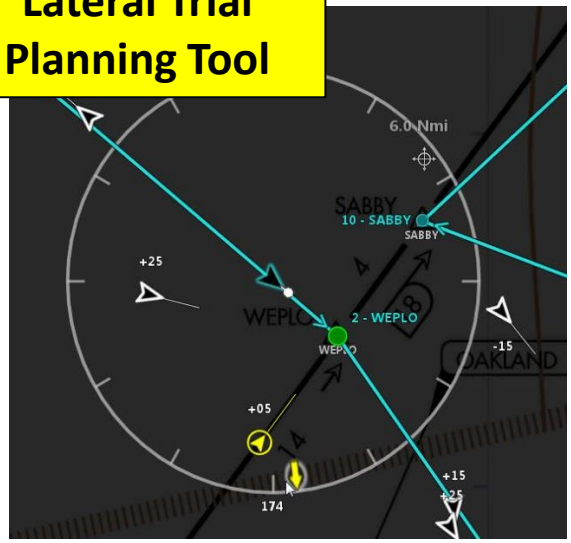
3. Omni Bands
   - Constantly displayed predicted threat level at nearby headings/altitudes
     - Green = regions that would maintain well clear
     - Yellow = regions that would trigger at least one Corrective alert
     - Red = regions that would trigger at least one Warning alert



Display Configurations

4. Vector Planner
   - Allowed pilots to test a single heading/altitude option for predicted threat level
     - Green = option would maintain well clear
     - Solid Yellow = option would trigger at least one Corrective alert
     - Solid Red = option would trigger at least one DAA Warning
   - Tool was off by default
     - Engaged by dragging vector arrow or clicking option on altitude tape
     - 5 second time-out

Lateral Trial Planning Tool



Vertical Trial Planning Tool

Method: Procedure

- DAA Pilot Task
  - Operate simulated MQ-9 through Class E airspace under Instrument Flight Rules
    - Maintain well clear with other aircraft
    - Four 37-minute scenarios
      - Two pre-filed flight plans
      - 9 scripted encounters with ownship
        - » 6 encounters would lead to loss of well clear without pilot action
    - Background traffic emulated busy day at Oakland Center (DOA 40/41)
      - Controlled by 'pseudopilots' via Multi-Aircraft Control Station (MACS; Prevot, 2002)
      - Sector managed by confederate ATC
  - Attend to secondary tasks
    - Chat messages requesting health/status information (e.g. fuel remaining)
    - Electronic checklists for system failure events

Measures

- Pilots completed post-trial and post-simulation questionnaires with subjective ratings pertaining to the preceding display configuration
  - Responses were analyzed using a one-way repeated measures Analysis of Variance (ANOVA)

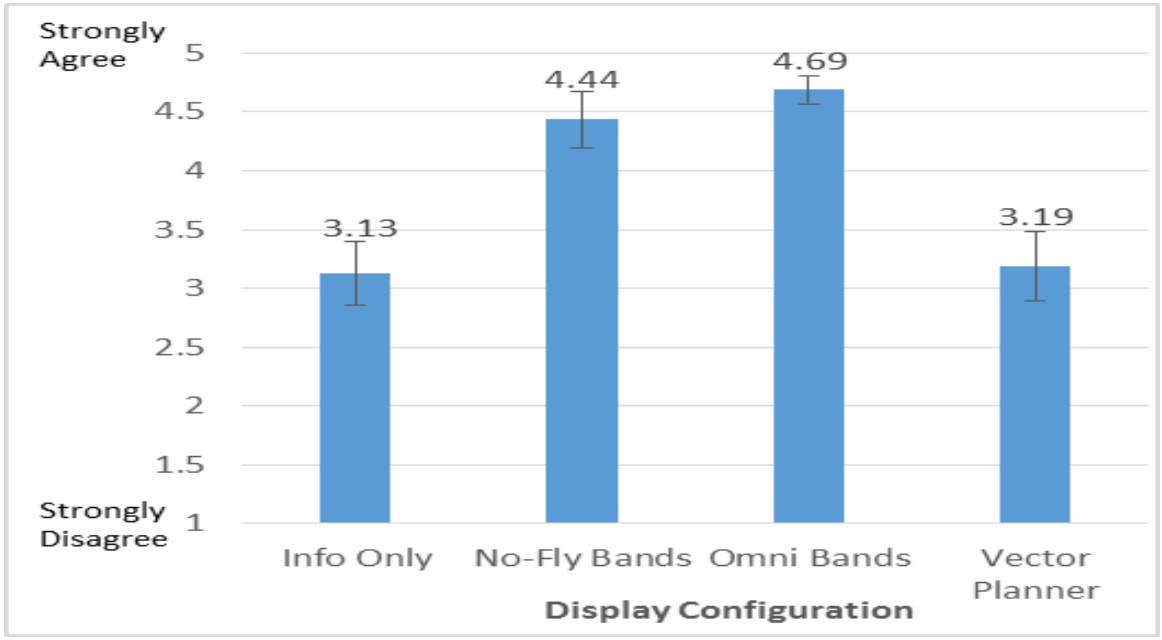
- Post Trial Questionnaire
  - Workload (NASA TLX)
  - Conflict Assessment and Avoidance
  - Ease of Use

- Post-Simulation Questionnaire
  - Information Sufficiency
  - Display Preference

$\alpha = 0.05$

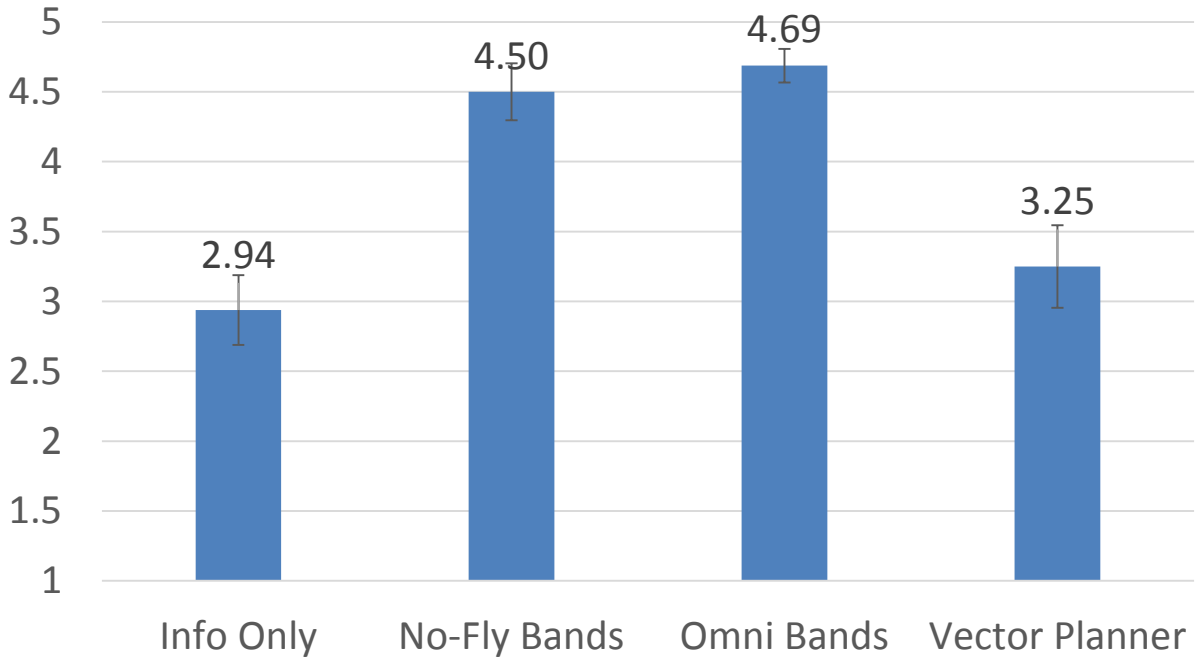
Results: Post-Trial

- Conflict Assessment
  - *'This display provided the information necessary to predict a potential loss of well clear'*
    - Omni Bands received higher assessment ratings compared to the Info Only and Vector Planner displays, $p < .001$
    - No-Fly Bands received higher assessment ratings compared to the Info Only display, $p<.05$



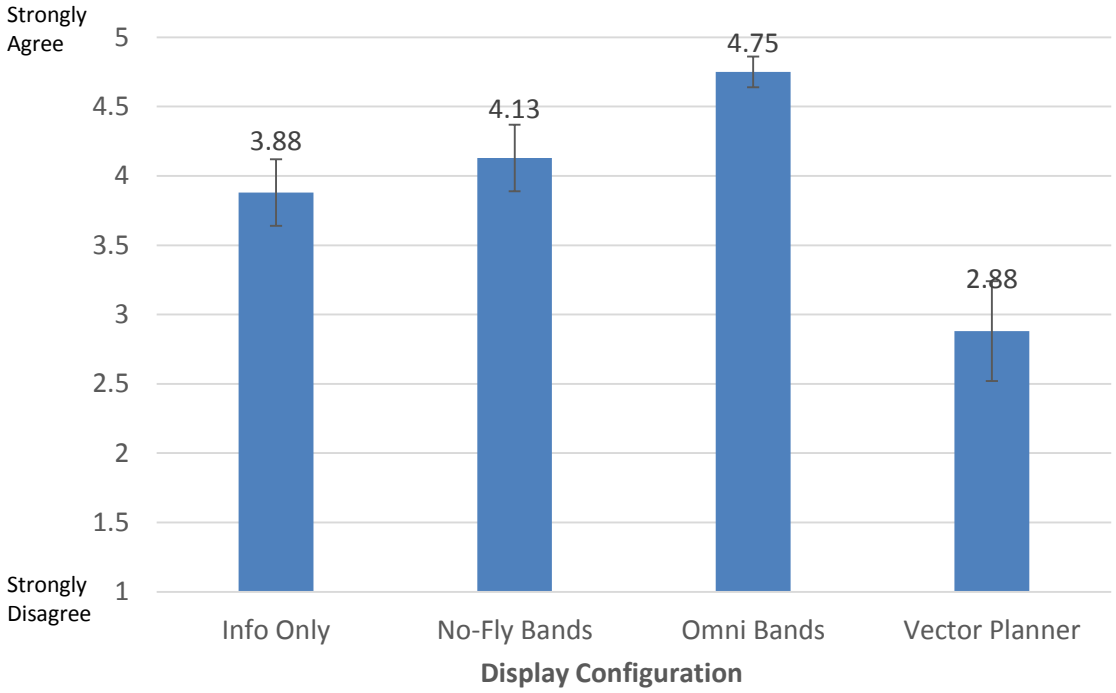
Results: Post-Trial

- Conflict Avoidance
  - *'This display provided the information necessary to perform avoidance maneuvers for well clear maintenance'*
    - Conflict avoidance ratings were greater for the No-Fly and Omni Bands displays compared to the Info Only and Vector Planner displays, $p < .001$



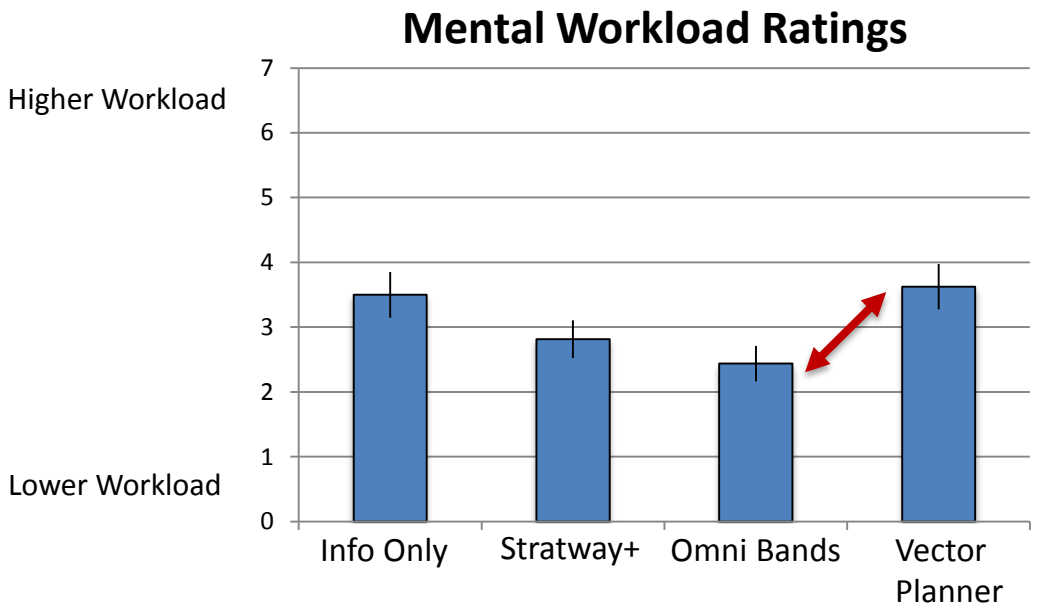
Results: Post-Trial

- Ease of Use
  - *'This display was easy to use'*
    - Pilots rated the Omni Bands display as easier to use than the Info Only, No-Fly Bands, and Vector Planner displays, $p = .001$
      - Info Only display was rated easier to use than Vector Planner, $p < .05$



Post-Trial: Workload

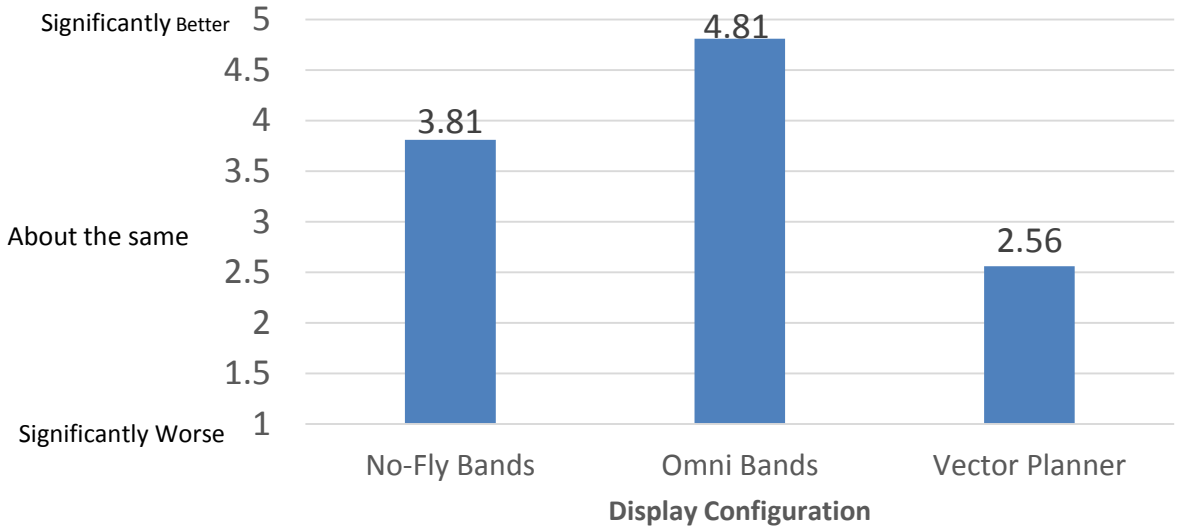
- Omni Bands resulted in significantly lower workload ratings than the Vector Planner for 5 of the 6 scales:
  - Mental, Temporal, Effort, Frustration, & Performance Degradation
    - Only Physical Demands failed to result in a significant difference



Results: Post-Sim

- Display Preference
  - *'Rank the displays in order of their effects on your ability to maintain well clear'*
    - Banding displays were most favored overall
      - 88% of pilots voted **Omni Bands** as the most beneficial
      - No-Fly Bands ranked second by 63% of pilots
    - Vector Planner received the lowest average ranking (ranked last by 50% of pilots)
    - Only one pilot rated Info Only display as top-2 preferred

  - *'How did the three suggestive guidance displays affect your ability to maintain well clear compared to Info Only?'*



Discussion

- Subjective ratings revealed that suggestive maneuver guidance in the form of banding is highly favored by UAS pilots
  - Information on all displays were rated as sufficient to DAA task performance overall
  - Banding displays rated most conducive to conflict detection and resolution
    - Provided guidance that was constantly visible to pilots
    - Omni Bands ranked most preferred and easiest to use
      - Indicated severity of potential threat(s)
      - Provided specific altitude values to achieve
    - Reduced cognitive workload compared to Vector Planner and Info Only
      - Vector Planner required manual activation that lasted just five seconds
        - » "Added an undesirable lag in decision-making"
        - » Only display rated difficult to use
  - Consistent with objective performance (Rorie et al., 2016)
    - Quicker response times and less well clear violations with the banding displays

Conclusion

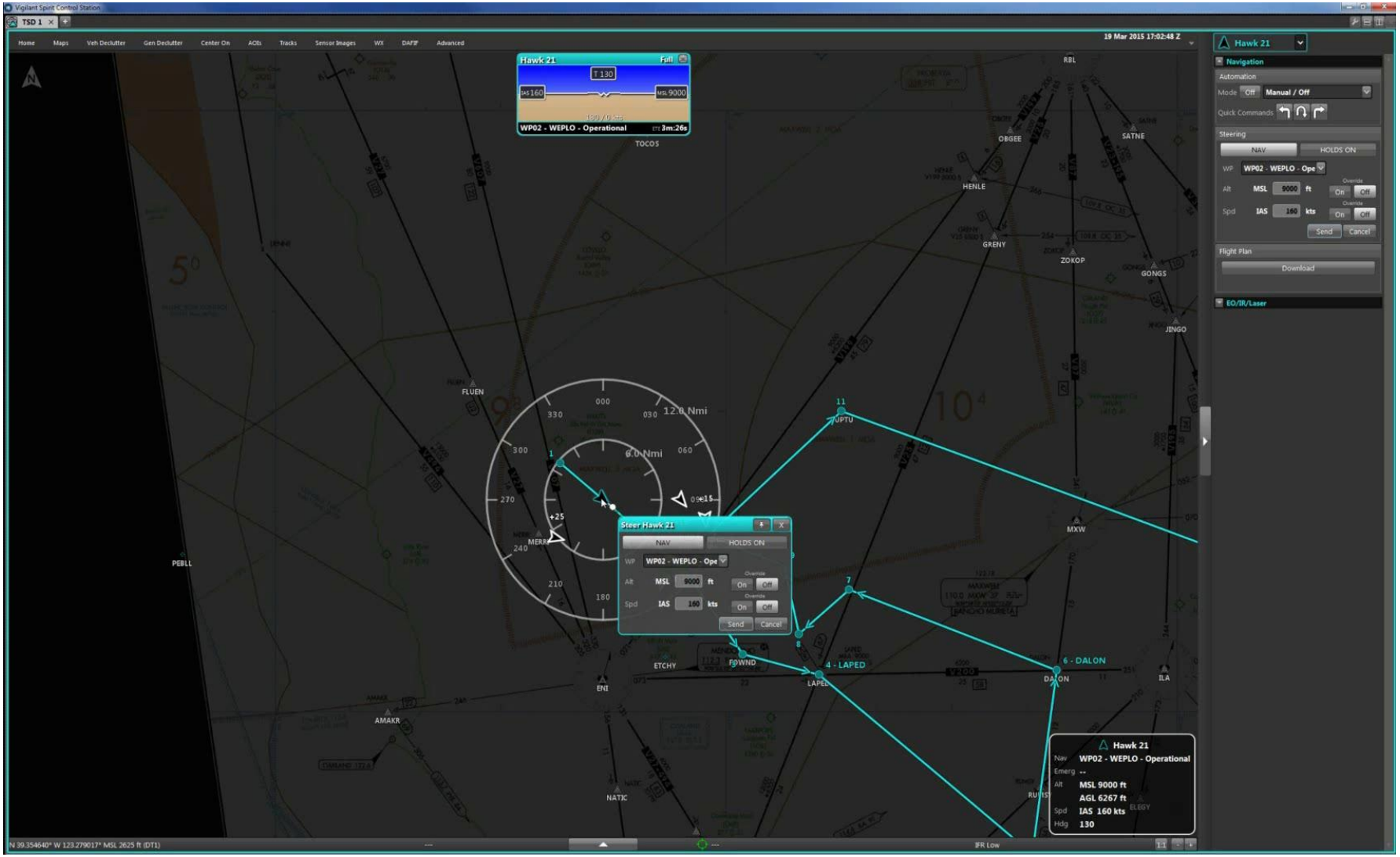
- Suggestive maneuver guidance in the form of banding is advantageous to pilot acceptability, response time, and performance

- DAA display considerations
  - Suggestive guidance that is not readily available may fare worse for task performance compared to no guidance at all if not implemented well
    - Trial planning tools previously rated more favorably when coupled with navigation interface in past research (Monk et al., 2015)
  - Further research needed to determine minimum information requirements
    - All displays rated as sufficient despite differences in subjective/objective performance
    - Interoperability with existing collision avoidance systems
    - Variations in aircraft performance, airspace environment, navigation interface, etc.

The End

Questions?

Display Conditions (VIDEO BACKUP)



Results: Post-Trial (Backup?)

- Task Performance
  - *'Rate your ability to handle all pilot responsibilities'*
    - Pilots indicated greater ability to handle DAA tasks in the No-Fly and Omni Bands displays compared to Info Only and Vector Planner, p = .001